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Failure Analysis and Surety Design of Composite Patching Systems

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Failure Analysis and Surety Design of Composite Patching Systems

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ABSTRACT

This work presents an experimental evaluation of patch repair of solid laminated composites. The study was focused on destructive and nondestructive tests of full-scale repaired panels under static tension loading conditions. The testing program consisted of ten panels: three pristine, three damaged, three repaired and one repaired with mismatched fiber orientation patch. The evaluated panels were (300 mm x 675 mm) in size and consisted of 6-ply ($(-60\ /60/0)_s$) quasi-isotropic laminates. The destructive tests were performed by North Carolina A&T State University and the nondestructive tests were performed by Iowa State University using Pulse-echo C-scan, Air coupled TTU and Auto-Tap. Sandia National Laboratories validated the NDT tests by implementing NDE field methods. Based on the evaluation performed in this study, it appears that the patch repair is an effective means in retrofitting damaged solid composite laminates.

Acknowledgements

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Introduction

Patch-repairs of composite structures are relatively new technology. Several reliability and survivability issues remain uncertain. Composite patching systems are attractive, in part, because the lay up of the reinforcing fibers can be optimized to handle the service conditions of aircrafts. However, the design must also anticipate the severe loading conditions that can occur in rough weather or during emergency evasive maneuvers. Proactively appraising the performance of composite patching systems under long-term normal service and short-term abnormal conditions is essential to ensure safety of repaired aircraft sections.

The subject of composite repairs has gained attention in the recent years Wang, (1); Bair (2); Armstrong (3) and Donalson (4). Robson (5) looked into the curing effects on the composite patch. He recommended of adding one more ply when a porous vacuum bag curing is used instead of the autoclaved counterparts. Zimmerman (6) performed a systematic investigation of the geometric effects on composite repairs. The focus of his investigation is to optimize the composite repair design in terms of the staking sequences. Zimmerman (7) presented an experimental evaluation of composite repairs of a glass/vinylester composite material with damage caused by impact loading. The focus of the investigation was on the repair angle. He concluded in his investigation that a bond line angle greater than 60^o can restore the undamaged composite strength. Heslehurst (8) provided 10-step guide to achieve a successful composite repairs. His techniques addressed the various schemes of inappropriate and poor repairs. Sung-Hoon (9 and 10) performed experimental study and analytical evaluation to check the effectiveness of techniques used for repairing damaged fiber reinforced composites.

Various parameters were investigated in light on the influence of each parameter on the repairs. The evaluated parameters were scarf angles, the number of external plies, moisture content, test temperature and temperatures applied at the time of repairs. His study provided practical procedures and recommendations for the most effective repairs.

Specimen Fabrication

Figure 1 shows a 6-ply quasi-isotropic laminated panel selected for this study. The selected configuration allows a reasonable panel thickness for repair and provides reasonable over all panel size that can be tested in the laboratory. The challenge in the full-scale testing is designing the grips that provide uniform stress distribution across the panel section. Three solid laminates were tested to validate the grip design and evaluate the strain along the mid-section. Panels were dented at the central point to present a damage zone. The damage area was removed according to Boeing design manual and three specimens were tested to evaluate the residual strength of the damaged panels. Scarfing was performed on four additional damaged panels and patch repairs were applied. The scarfing was performed on one side of the panel with 12.5 mm steps. Figure 2a shows the scarfed laminated panel that was performed layer by layer and Figure 2.b shows the repaired panels after the application of the patch. The retained strength was also evaluated by testing four repaired panels in which one panel was repaired with wrong plies orientations. All repairs performed in this program complied with Boeing Standards.

The repaired panels were shipped to Iowa State University's Center for Nondestructive Evaluation Airworthiness Assurance Center of Excellence for NDT evaluation that is to ensure the soundness of the repair. The NDT C-scan is shown in Figure 3. The images shown in Figure 3 indicate good repairs without any apparent flaws.

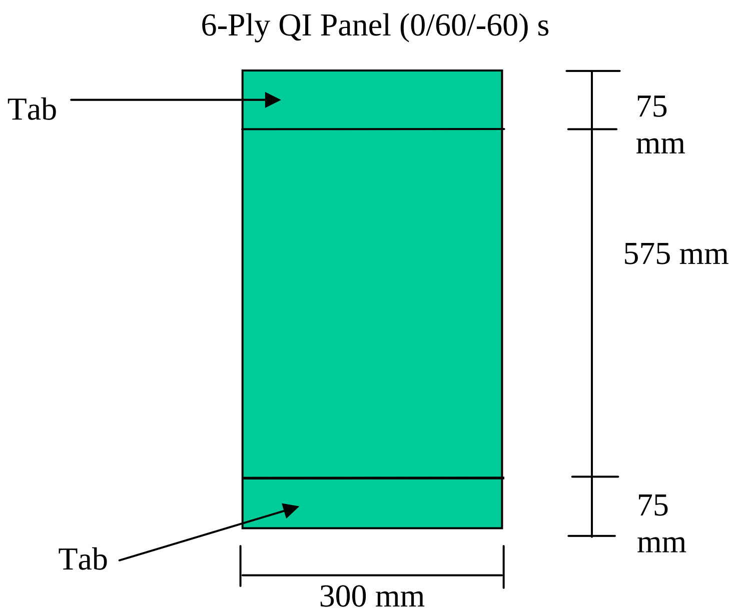


Figure 1. Full Scale panel.

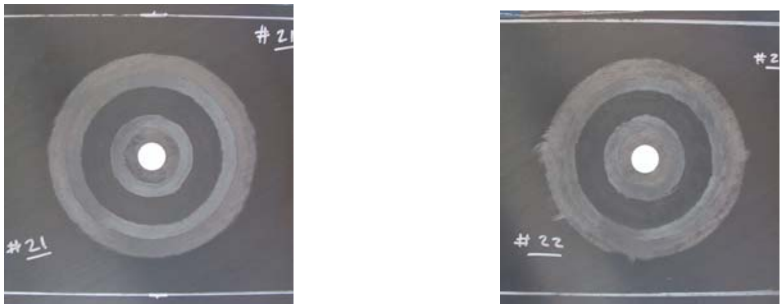


Figure 2.a Scarfed panels (# 21 and 22)

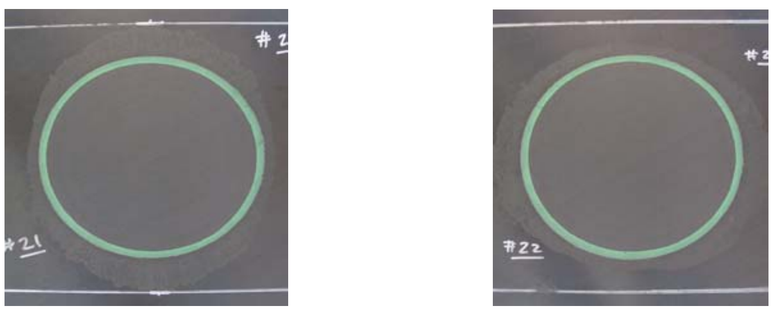


Figure 2.b Repaired panels

Figure 2. Scarfed and Repaired Panels

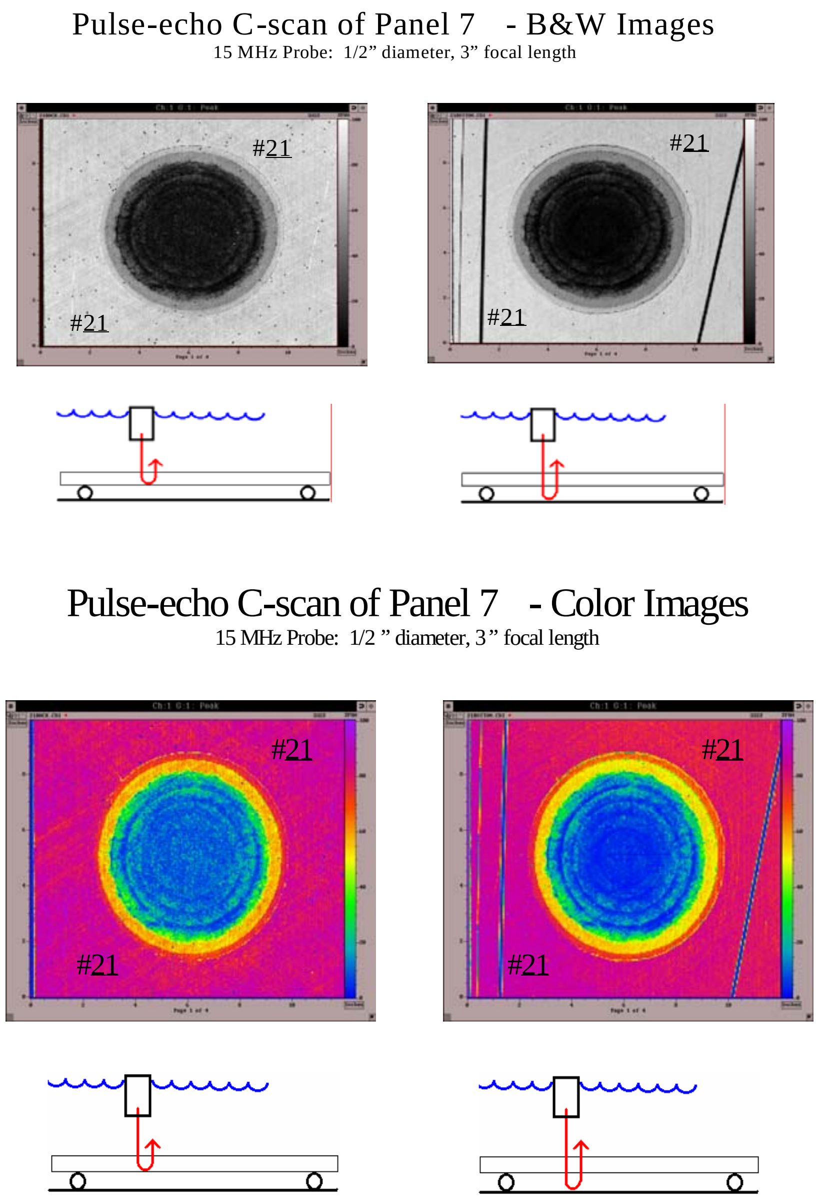
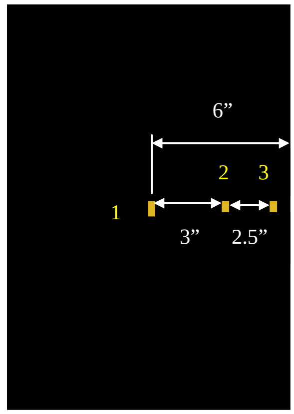
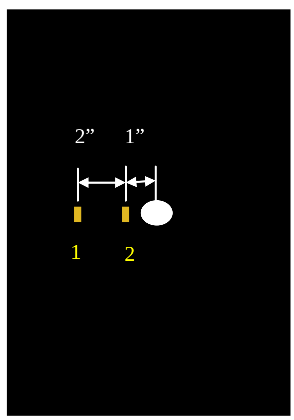


Figure 3 NDT scan of patched panels

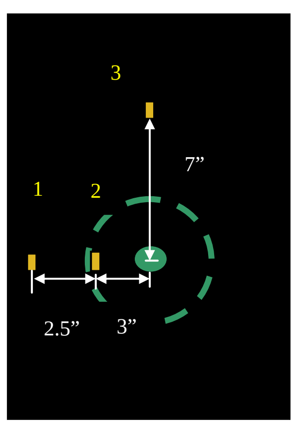
Strain Gauges were mounted on tested panels at different locations of interest. Schematic diagrams for the strain gauges locations on one pristine panel, one damaged and one repaired panel are shown on Figure 4.



Undamaged (Pristine Panel)



Damaged Panel (1” centered hole)



Back Side of Patch-Repaired Panel

Figure 4: Locations of Strain Gauges

Test and Test Results

Load stroke controlled MTS machine was used to test the specimens. Panels were loaded by 0.5 inch stroke displacement/min. The strain and the load were recorded continuously using Vishay's system 5000 data acquisition system for all strain Gauges shown in Figure 4.

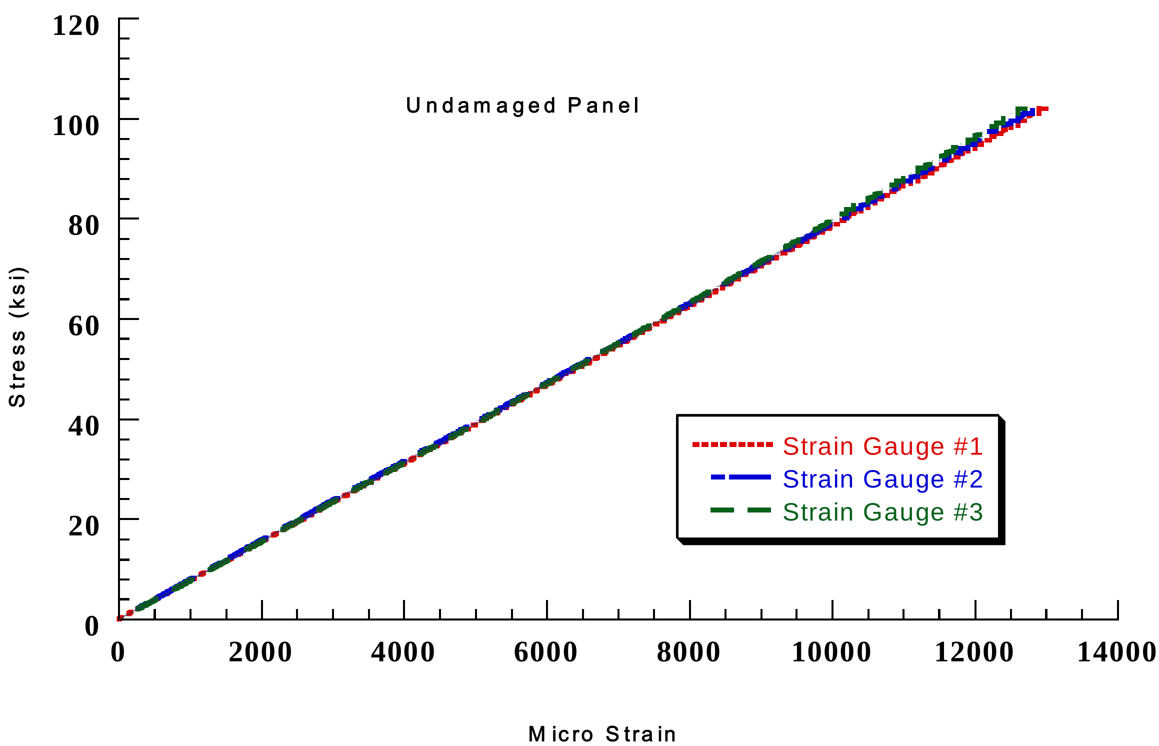


Figure 5a Pristine Panels

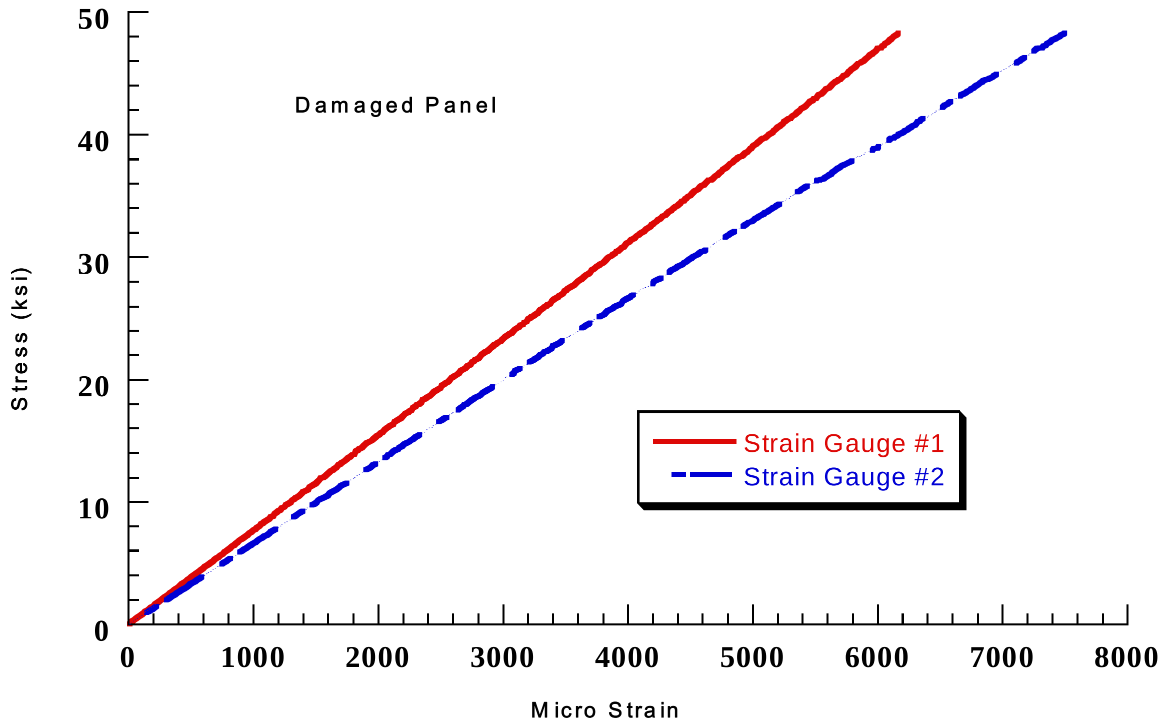


Figure 5b Damaged panels

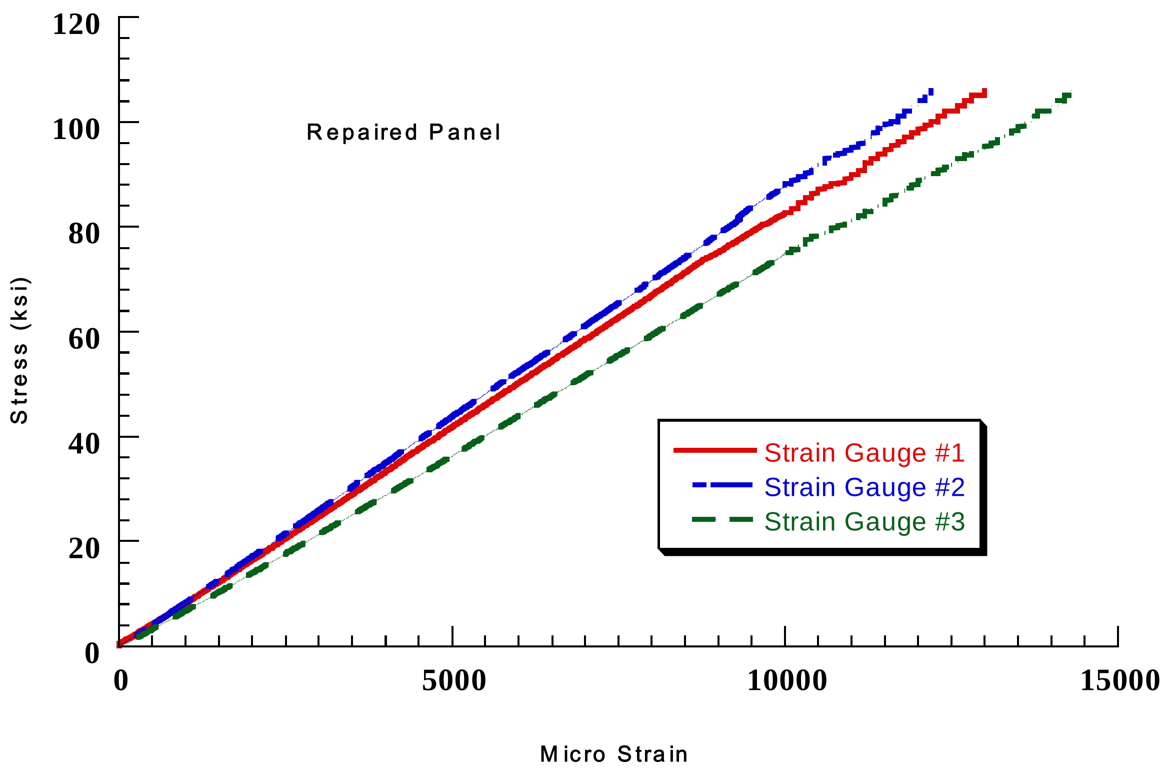


Figure 5c Repaired Panels

Figure 5: The stress-strain diagrams for the gauges mounted on (a) Pristine panel, (b) damaged panel and (c) repaired panel.

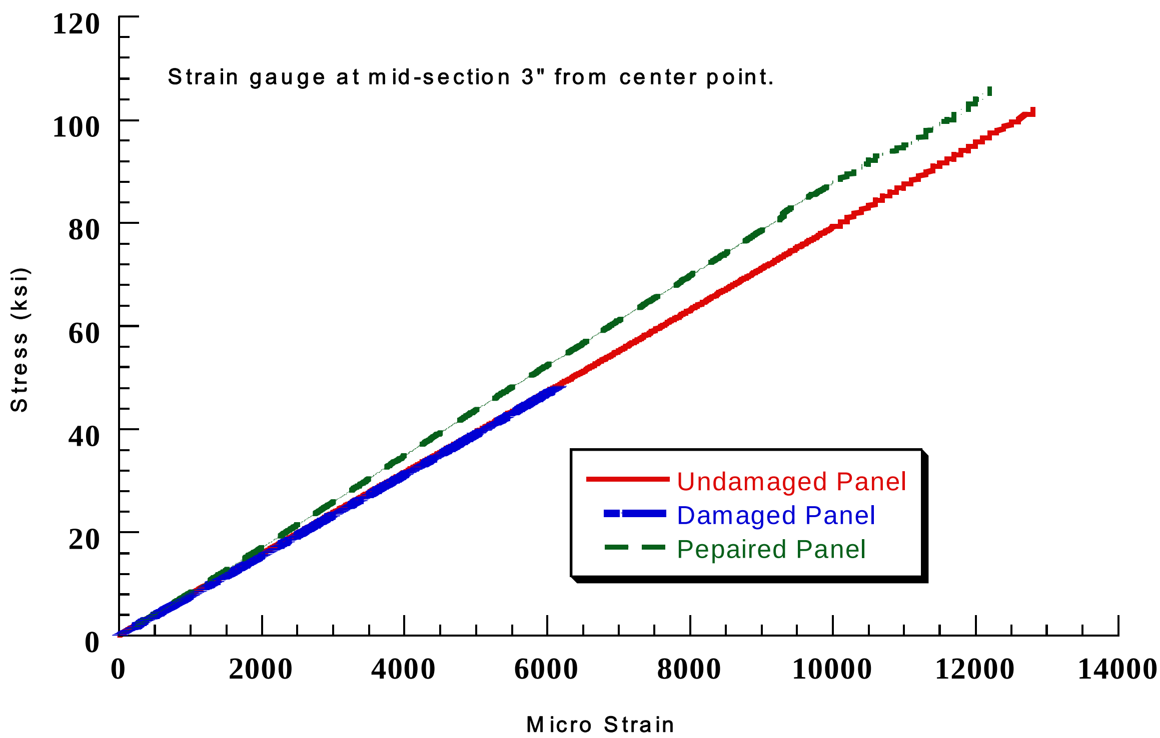


Figure 6: Comparison between strain gauges on the three panel types.

The stress-strain behavior shown in Figure 6 indicates that the patch increases the stiffness of the panel in comparison with the pristine panel.

Figure 7 shows that the failure in the repaired panel took place at mid-section of the specimen.

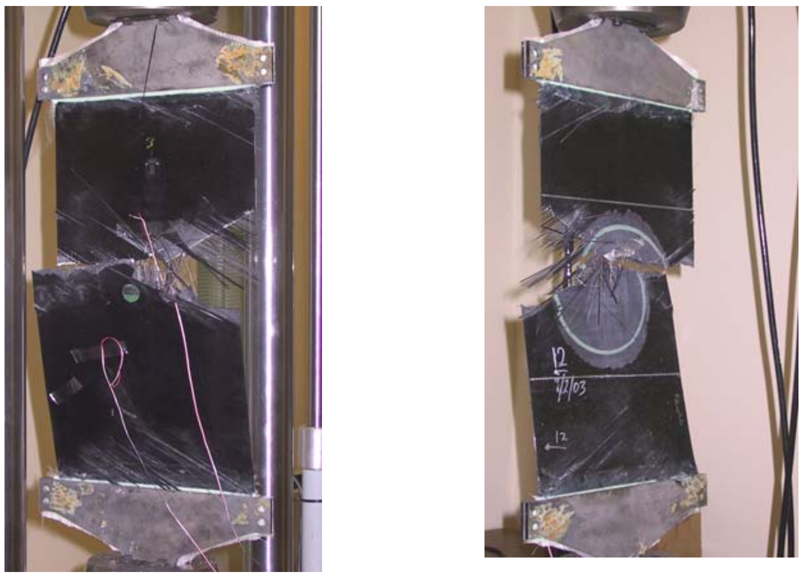


Figure 7: Failed repaired Specimen.

Table 1 presents the summary of the results obtained by the testing program. The pristine panels failed on an average load of 191 KN at a stress level of 736 MPa. The damaged panels failed on an average load of 82.2 KN on an average stress of 315.8 MPa. The repaired panels failed on an average load level of 172.2 KN (663.2 MPa axial stress). The testing results indicated that the repaired panel’s strength is about 90 percent of the pristine panel. Also, the results indicate that the strength of the repaired panels is more than twice of the damaged panels. Table 1 shows also that the patch repair is a superior. The failure load of the wrongly oriented fibers did not influence the failure loads of the repaired specimen. The failure load of the wrongly applied patch was 147 KN that is within the tolerance of the repaired panels. This should be verified with more testing.

Table 1. Results of the Testing Program

Cat. Number	Test Configuration	Failure Loads (KN)	Failure Stress (MPa)	Average Loads (KN)	Average Stress (MPa)
1	Pristine	161.2*	619*		
2	Pristine	174.4	670		
3	Pristine	208.8	802	<u>191.6</u>**	<u>736</u>**
4	Damaged	77.4	303.6		
5	Damaged	83.5	320.9		
6	Damaged	85.7	329.2	<u>82.2</u>	<u>315.8</u>
7	Repaired	183.5	704.9		
8	Repaired	154.3	592.9		
9	Repaired	180.2	691.9	<u>172.7</u>	<u>663.2</u>
10	Repaired***	147.2	577.4	<u>147.2</u>	<u>577.4</u>

* Premature Failure due to grip slippage.

** Average of two tests (2 and 3).

*** Repaired with wrong ply orientation.

Summary

The objective of this testing program was focused on evaluating the use of scarf repair as a retrofitting technique for upgrading damaged solid composite laminates. The investigated repairs were performed in accordance with the Boeing standards. Based on the test performed in this study, the following can be concluded:

1- Scarf repair is an effective retrofitting technique of defected solid composites.

2- Repaired panels performed as expected under static tensile testing conditions

3- Scarf repair restores about 90 percent of the undamaged Solid composites.

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